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Special Computer Section

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# Research & Development®

# DEGRADABLE PLASTICS

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Does your salary measure up?

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Thin films shrink as research heats up

*Research Triangle's Anthony Andrady tests degradability of plastics in water*

INTERNATIONAL MAGAZINE OF RESEARCH AND DEVELOPMENT

R&D

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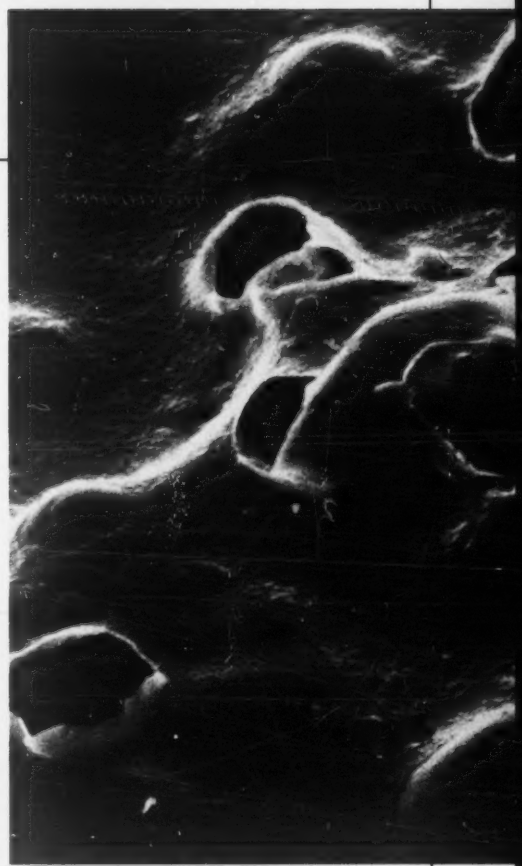
# FEATURES



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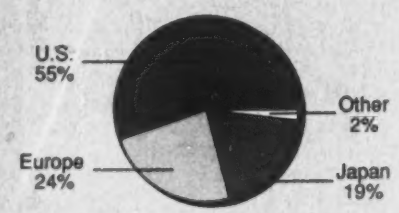
## Human genome R&D pushes equipment sales

THE MOLECULAR BIOLOGY equipment market will grow more than 22% annually to exceed $450 million by 1993, according to analyst Alexandra Straus of Strategic Directions Intl., a Los Angeles-based market consulting firm.

The U.S., which accounted for 55% of 1988 sales, will remain the largest market sector with most instruments used for human genome R&D. "However, Asian and European markets will grow faster," says Straus.

U.S.-based manufacturers, such as Applied Biosystems, DuPont, and Hewlett-Packard (with its purchase of Applied Protein Technologies), dominate the molecular biology equipment market, which includes such instruments as DNA sequencers and synthesizers. □

### U.S. biggest consumer of biological instruments




Source: Strategic Directions Intl.

*U.S. human genome research will retain its position as the largest market sector for automated molecular biology equipment at least through 1995, says market analyst Alexandra Straus.*

## Control Data tests export laws with Soviet computer order

THE SINCERITY of the Bush Administration's Malta summit support of nuclear-safety research is being tested by Control Data. The Minneapolis-based company has submitted a mainframe computer order from the Soviet Union to the U.S. Dept. of Commerce (DOC) for export approval. The computers are intended for Soviet nuclear research.

Current U.S. trade law prevents export to the Soviet Union of computers that can process more than 78 Mbit/sec. Each of the six Cyber 962-11 computers that Control Data wants to sell can process 435 Mbit/sec.

Control Data already has exported this same mainframe model to China for weather research. DOC performance restrictions for China are 550 Mbit/sec. "China is not seen as a military threat," says Control Data spokesman David Lindsey.

Soviet researchers plan to use the mainframes to analyze the safety standards of existing nuclear plants, assist in the design of new plants, simulate accident scenarios, and help in the decommissioning or renovation of many plants, including the Chernobyl complex and the superheating reactor at Beloyarsk which has been shut down.

The 962-11 computers exceed anything Soviet nuclear researchers currently have. Soviet officials say their existing reactors are safe, but "it is not enough to demonstrate safe operation," says Eugene Adamov, director of the Soviet's R&D Institute of Power Engineering (RDIPE), Moscow.

The Soviets want to use these computers to modify the design of their reactors to better tolerate malfunctions. The computers will be located at RDIPE, the Hydropress Experimental Design Bureau (Podolsk), the Special Machine Building Design Bureau (Gorkij), and the Chernobyl Complex Expedition (Moscow).

U.S. national security concerns were considered in this sale and safeguards have been identified, including on-site monitoring by U.S. personnel according to James Ousley, president of Control Data's Computer Products Group.

Control Data representatives express confidence that DOC export approval can be obtained by late spring 1990. An application then would be submitted to the multinational Coordinating Committee for Multilateral Export Controls (Cocom).

If the U.S. approves the sale, Cocom most likely also would give its approval. This would have the computers in place and operating by late summer 1990. —*Tim Studt*

*Soviet researcher Eugene Adamov says "Computers [from the U.S.] will enable us to bring our nuclear reactors up to international safety standards."*

### Japan picks the world's 10 best companies

| 1989 | 1988 | | Hdqtrs. |
|---|---|---|---|
| 1 | 1 | IBM | U.S. |
| 2 | 2 | Glaxo Holdings | UK |
| 3 | 9 | Royal Dutch/ Shell | Neth., UK |
| 4 | 7 | Exxon | U.S. |
| 5 | 45 | Dow Chemical | U.S. |
| 6 | 10 | General Motors | U.S. |
| 7 | 5 | British Telecom | UK |
| 8 | 6 | Ford Motor | U.S. |
| 9 | 4 | Digital Equip. | U.S. |
| 10 | 45 | American Home Products | U.S. |

FOR THE FOURTH year in a row, IBM was ranked as the world's best company in an annual survey conducted by Nihon Keizai Shimbun Inc., publisher of the English-language *Japan Economic Journal*.

Items such as asset base, profitability, stability, and financial performance were considered in ranking companies in 20 countries.

High-tech electronic, pharmaceutical, chemical, and multinational automotive companies dominated the survey's upper rankings.

# You'll Be Better Paid in 1990, Despite the Shaky Economy

People in R&D enter the 1990s with fatter paychecks, thanks mostly to increasing age and experience.

*By **Robert R. Jones**, Executive Editor,* R&D Magazine

FOLLOWING A YEAR of weak corporate earnings with a shaky world economy, most workers in research, development, and quality assurance are better off—or, at least, no worse off—than they were 12 months ago.

A careful look at this year's industry profile, based on an exclusive survey of nearly 3,800 readers of *R&D Magazine*, reveals an R&D work force that is decidedly different from the one that entered the previous decade.

Compared with the R&D work force of 1980, workers now in research, development, and quality assurance are older, more knowledgeable, and far more well-to-do.

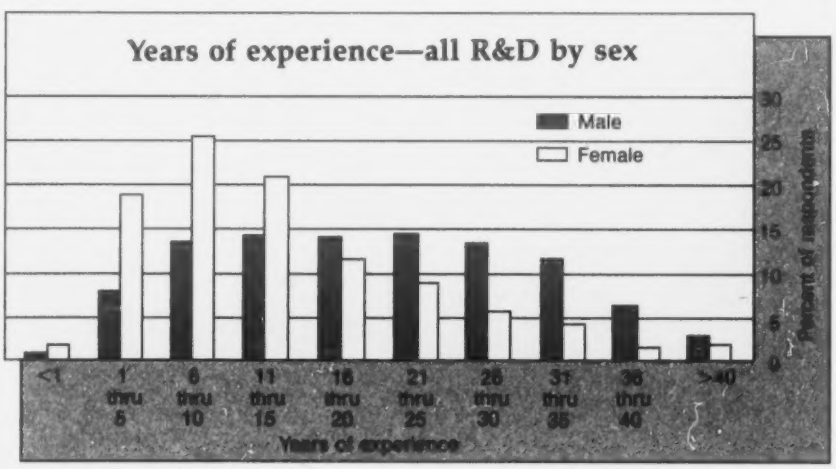
The salary range for R&D workers continues to expand, as it has for more than 15 years, with the upper end climbing while the lower end remains essentially stationary.

Only 4% of our 1980 respondents listed an annual salary of $46,000 a year or more. The most populous single salary span that year was $25,000 through $27,999. (In those years our salary scale covered $3,000 spans. As the salary range expanded, the charts became so crowded that we changed to the $5,000 spans that we use now.)

By 1985, the portion of respondents earning $45,000 or more was 35.1%, with the most populous span being $40,000 through $44,999. Today, 60.8% of our respondents report annual salaries of $45,000 or more, an increase of 56% in 10 years. The most populous span (with 13.2%) is $50,000 through $54,999.

The median income for this year's respondents is $49,632, up 4.7% from last year's $47,417. This increase is only half as large as last year's (9.2%), but stands well above 1988's increase of 0.42%.

The 1989 increases, now in effect, follow a year with a relatively low inflation rate. For nearly half of the respondents, their salary increases more than kept them even with inflation.




### $30 billion payroll

With these rising figures you continue to be part of an affluent demographic segment. Workers in research and development in the United States will draw a total paycheck in 1990 of $29.8 billion, up impressively from $24.1 billion in 1985.

The biggest salary increases went to chemical engineers, with 40.8% getting raises of 6% or more last year. They were followed by biologists (40.0%) physicists (34.5%), and chemists and mechanical engineers (tied at 33.8%).

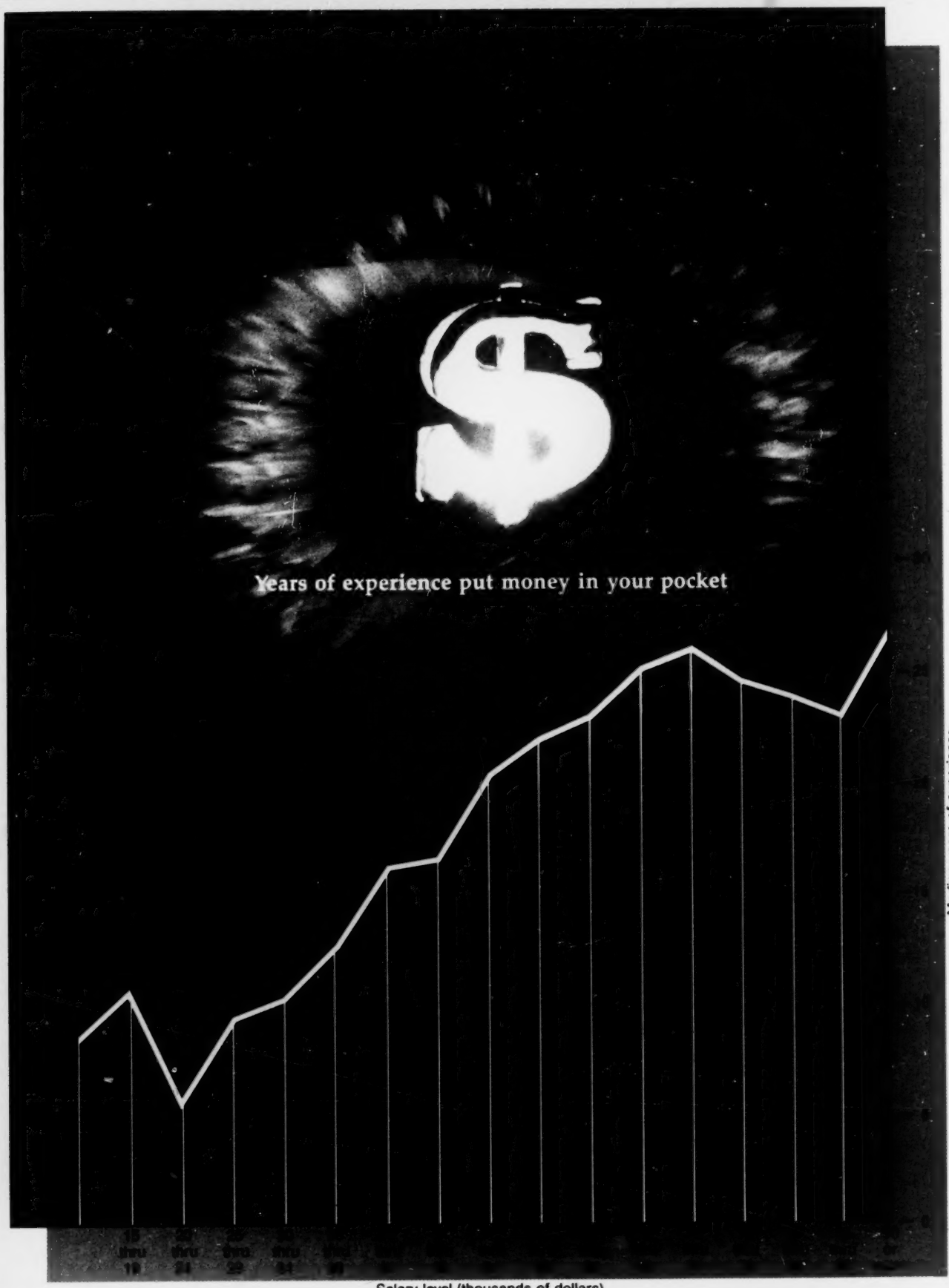
Mathematicians were at the low end of the group with none reporting a salary increase of 10% or more, although nearly three fourths of them reported increases of 6% through 9% (see accompanying table).

The percentage of respondents receiving no salary increase last year (9.2%) is similar to 1989's (9.3%) and far below the three preceding years, which peaked with 16.5% getting no raise in 1987. Remember, however, that this group includes a substantial percentage of new hires.

### Aero engineers lead

Looking at median salaries by discipline, aeronautical engineers held onto first place for the third year in a row despite a 2.4% decrease from last year's reported median. Aeronautical engineers also top our charts for both age and experience, with one in eight being older than 65.

Mathematicians (up 17.6%) and industrial engineers (up 21.9%) made the strongest median salary gains over


Years of experience put money in your pocket
Median years of experience
Salary level (thousands of dollars)

# Veteran scientists and engineers earn rewards for years spent doing research and development.

last year. As did aeronautical engineers, metallurgists reported lower salaries this year (median down 0.5%), falling three places in the discipline rankings chart.

In last year's report, we called attention to the $19,000-plus span between the median incomes of industrial engineers ($38,125) and aeronautical engineers ($57,500). This year, industrial engineers did a lot of catching up, while aero engineers slipped a little.

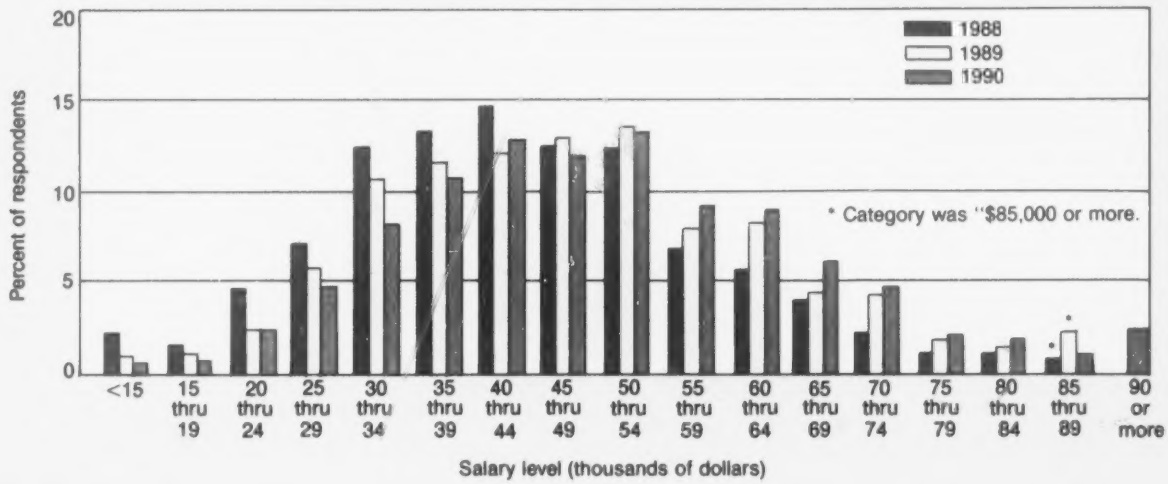
Now the gap is down to $9,663, but even with that adjustment, median salaries for aero engineers still are 20% greater than those for industrial engineers (and biologists, who now are at the bottom in the ranking).

Throughout the 1980s, the median age of respondents to our survey has moved steadily upward, with the median age in 1980 being 40.4 years, in 1985 42.0 years, and now 44.4 years.

### Dollars for experience

Likewise, the median years of experience for our respondents has increased from 15.4 years in 1980 to 16.5 years in 1985, and now stands at 18.7 years.

## Salary levels for all R&D (three years compared)




| All disciplines compared | 1989 salary raise amount | | | | | | 1990 salary range | | | Years with present employer | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | None (%) | Less than 2% (%) | 2 thru 5% (%) | 6 thru 9% (%) | 10 thru 13% (%) | 14% or more (%) | Median | <$15,000 (%) | >$90,000 (%) | Median | <1 (%) | >36(%) |
| **Aeronautical engineer** | 3.3 | 4.9 | 63.9 | 13.1 | 11.5 | 3.3 | $56,111 | — | 3.2 | 9.4 | 3.2 | — |
| **Biologist** | 5.0 | 2.0 | 53.0 | 27.5 | 7.0 | 5.5 | 46,315 | 0.5 | 1.5 | 9.3 | 3.9 | 1.0 |
| **Ceramist** | 7.9 | — | 66.7 | 19.0 | 3.1 | 3.3 | 53,250 | — | — | 5.7 | 6.3 | 3.2 |
| **Chemical engineer** | 7.9 | 0.4 | 50.9 | 32.1 | 6.1 | 2.6 | 52,931 | 0.4 | 3.4 | 8.8 | 5.6 | 1.9 |
| **Chemist** | 8.8 | 1.8 | 55.6 | 25.5 | 5.8 | 2.5 | 48,312 | 0.8 | 2.4 | 10.2 | 4.0 | 1.0 |
| **Electrical engineer** | 12.2 | 2.8 | 52.9 | 22.0 | 6.5 | 3.6 | 50,978 | 1.0 | 1.8 | 9.2 | 4.1 | 2.3 |
| **Geologist** | 13.3 | 6.7 | 50.1 | 29.9 | — | — | 51,250 | 3.3 | 3.1 | 8.1 | 6.5 | — |
| **Industrial engineer** | 5.7 | — | 65.7 | 20.0 | 2.9 | 5.7 | 46,500 | 2.7 | — | 11.1 | 2.7 | 5.4 |
| **Mathematician** | 5.5 | 5.7 | 72.2 | 16.7 | — | — | 49,999 | — | — | 15.0 | — | — |
| **Mechanical engineer** | 11.5 | 1.6 | 53.1 | 25.2 | 5.5 | 2.8 | 49,280 | — | 1.0 | 7.9 | 5.2 | 2.4 |
| **Metallurgist** | 7.5 | 3.7 | 65.8 | 18.2 | 3.2 | 1.6 | 51,928 | 0.4 | 0.6 | 9.1 | 3.1 | 1.0 |
| **Physicist** | 9.5 | 3.0 | 53.0 | 26.3 | 6.2 | 2.0 | 54,500 | 0.3 | 2.9 | 10.2 | 2.3 | 1.6 |

## Increases in rate of pay*

| Amount of increase | 1990 | 1989 | 1988 | 1987 | 1986 | 1985 |
|---|---|---|---|---|---|---|
| | Percent of respondents | | | | | |
| None | 9.2 | 9.3 | 14.5 | 16.5 | 11.3 | 9.3 |
| Less than 2% | 2.1 | 5.3 | 6.3 | 4.3 | 3.6 | 2.9 |
| 2 through 5% | 54.9 | 54.8 | 49.8 | 39.2 | 37.1 | 36.6 |
| 6 through 9% | 24.7 | 22.2 | 21.7 | 30.8 | 36.3 | 37.6 |
| 10 through 13% | 5.9 | 5.6 | 4.7 | 6.0 | 8.3 | 10.1 |
| 14% or more | 3.2 | 2.7 | 3.0 | 3.2 | 3.3 | 3.6 |
| Ahead of inflation | 46.5 | 44.2 | 46.0 | 79.2 | 60.1 | 63.3 |

* Granted in preceding year for year shown

## Discipline rankings by median salaries

| Rank 1990 | Rank 1989 | Discipline | Median salary 1990 | Median salary 1989 | Percent change |
|---|---|---|---|---|---|
| 1 | 1 | Aero. engineer | $56,111 | $57,500 | -2.4 |
| 2 | 3 | Physicist | 54,500 | 51,087 | 6.7 |
| 3 | 4 | Ceramist | 53,250 | 50,500 | 5.4 |
| 4 | 7 | Chem. engineer | 52,931 | 49,100 | 7.8 |
| 5 | 2 | Metallurgist | 51,928 | 52,205 | -0.5 |
| 6 | 4 | Geologist | 51,250 | 50,500 | 1.5 |
| 7 | 6 | Elec. engineer | 50,978 | 50,185 | 1.6 |
| 8 | 11 | Mathematician | 49,998 | 42,500 | 17.6 |
| 9 | 8 | Mech. engineer | 49,280 | 48,900 | 0.8 |
| 10 | 9 | Chemist | 48,312 | 45,243 | 6.8 |
| 11 | 12 | Indust. engineer | 46,448 | 38,125 | 21.9 |
| 12 | 10 | Biologist | 46,315 | 43,846 | 5.6 |

When salary is correlated to experience (see accompanying chart), this premium for experience becomes more obvious. For this year's respondents with less than a year's experience, the median income is $32,083.

Median for those with one through five years is $35,132. For six through 10 years, it is $42,244, and so it goes, rising to a median annual salary of $54,423 for those with more than 40 years' experience.

The percentage of respondents with PhD degrees has moved from 27.6% in 1980 to 33.1% in 1985, and now stands at 31.6%. Biologists lead the disciplines in the percentage with a PhD, as they did in 1989. Physicists retain second place. More than half of the respondents in both of these disciplines have PhD degrees.

Geologists again are in third place, with nearly half of the respondents having doctorates. Mechanical engineers have the lowest percentage of PhDs at 10.9%.

When master's degrees and doctorates are considered together and the disciplines are ranked for advanced degrees, geologists and biologists are tied for the lead with more than 80% (80.7% and 80.6%) having an advanced degree.

Physicists are next in order at 75.1%, followed by mathematicians, 72.2%; ceramists, 71.4%; and aeronautical engineers, 71.0%.

In the second part of this report, we will look into the implications of some of the above conclusions and also report on the value of an advanced degree to its holder, relative salary scales of men and women, and the advantages or disadvantages in salaries for jobs in industry, government, or university. **R&D**

| | Age, years | | | Experience, years | | | Highest academic degree | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Median | <26 (%) | >65 (%) | Median | <1 (%) | >40 (%) | <BS (%) | BS (%) | MS (%) | PhD (%) |
| | 47.9 | 3.2 | 12.9 | 24.6 | — | 9.7 | 3.2 | 25.8 | 51.6 | 19.4 |
| | 43.3 | 1.0 | 3.4 | 16.1 | — | 2.9 | 1.0 | 18.4 | 23.8 | 56.8 |
| | 41.9 | — | 1.6 | 16.7 | — | 1.6 | 3.2 | 25.4 | 31.7 | 39.7 |
| | 44.6 | 1.8 | 2.0 | 18.3 | 1.4 | 1.6 | 1.5 | 46.8 | 29.6 | 22.1 |
| | 44.5 | 1.5 | 2.5 | 18.8 | 0.5 | 1.8 | 4.2 | 36.2 | 19.2 | 40.3 |
| | 44.7 | 3.2 | 3.4 | 20.1 | 1.0 | 3.3 | 17.4 | 36.4 | 33.4 | 12.8 |
| | 41.5 | — | 3.2 | 15.5 | — | — | 9.6 | 9.8 | 32.3 | 48.4 |
| | 45.6 | — | 2.7 | 22.2 | — | 2.7 | 29.7 | 35.1 | 18.9 | 16.2 |
| | 47.5 | — | — | 20.9 | — | — | 5.6 | 22.2 | 38.9 | 33.3 |
| | 44.7 | 2.6 | 3.6 | 19.7 | 0.8 | 3.4 | 14.3 | 45.4 | 29.4 | 10.9 |
| | 44.3 | 1.0 | 1.6 | 18.8 | 0.4 | 0.6 | 5.2 | 30.2 | 26.0 | 38.5 |
| | 45.4 | 1.8 | 2.0 | 19.5 | 0.3 | 1.9 | 2.9 | 22.0 | 22.7 | 52.4 |

**READER RESPONSE PANEL**

Please rate your interest in this article by circling the appropriate number on the Reader Service Card.

High **389** Medium **391** Low **393**

# Thin Films Get Thinner As Research Heats Up

## Processing is more difficult for submicrometer thin films, but gains outweigh the problems.

*By* ***Tim Studt,*** *Associate Editor,* R&D Magazine

SUCCESS BREEDS success as the saying goes. The tremendous improvements that thin-film coatings contribute to semiconductors, optics, and machine tools are driving researchers to develop thinner, stronger, and a greater variety of thin-film materials.

Researchers now regularly use chemical vapor deposition (CVD), molecular beam epitaxy (MBE), and ion-bombardment processes to fabricate new materials and structures that offer vast improvements in properties over current materials.

The most dominant areas for thin-film research, other than semiconductors, are hard coatings, optical coatings, magnetic storage media, and high-temperature superconductors.

### Submicrometer semiconductors

In semiconductor production, most companies are at the 1.5-to 2-μm thin-film structure level, more advanced firms are at 1.0 to 1.5 μm, and the most advanced ones are at 0.5 to 1 μm.

Going smaller than 0.5 μm poses special processing problems, according to Arnold Reisman, vice president of semiconductor research and technology at the Microelectronic Center of North Carolina (MCNC), Research Triangle Park.

He lists several problems that MCNC's industrial affiliates, which include IBM, say must be solved before production of sub-half-micrometer devices will be practical.

One problem involves high-frequency signals that cause the current in a wire to be carried on the wire's surface. In 0.5-μm ultralarge scale integration devices, this effect results in attenuation of the signal and degradation of the waveform.

The effect even occurs in high-temperature superconductors and is most prevalent in chip interconnections. Optical thin films are being tested as an interconnection material to eliminate the signal degradation.

A second problem involves tungsten deposits, which can grow on mask throughholes and cause electrical shorts.

Researchers at MCNC have developed an etching process that removes tungsten from the mask faster than from the substrate. This process allows you to remove all of the buildup on a mask while removing only a small amount from the substrate.

Another problem Reisman notes is that while contaminants in the ambient air, process gases, and process liquids can be filtered to less than 0.5 μm, processing equipment contributes particulates at sizes and levels that can affect product yield.

Most U.S. equipment producers don't have the resources to devote to solve this problem. Only large, vertically integrated Japanese companies, such as Nikon and Canon have the ability to fund research to eliminate this problem.

Lithographic light sources are another problem area for devices with less than 0.5-μm dimensions. "The 248-nm-wavelength xenon fluoride laser will enable us to build 0.25-μm devices," says Reisman.

But, to obtain smaller structures, 193-nm sources, such as those from argon fluoride excimer lasers, will be needed. However, 193-nm light quickly creates defects—radiation damage—in the quartz laser lenses. These defects diffuse the beam, making it difficult to maintain the necessary beam width.

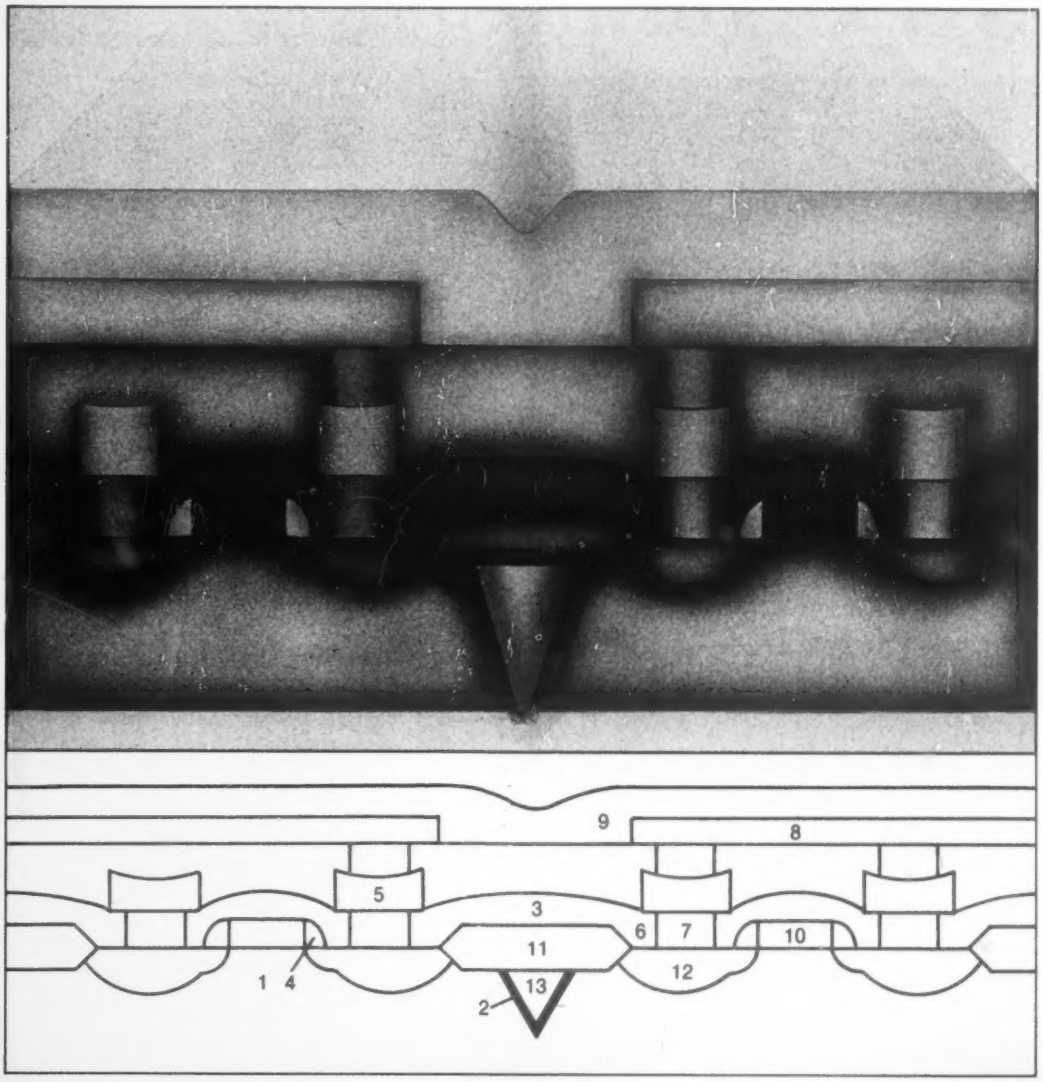
Tests at MIT's Lincoln Lab, Cambridge, reveal that these defects are permanent and do not anneal at room temperatures even after a year. Japan's Matsushita researchers design thin lenses that reduce light absorption to minimize the defects.

X rays can be used as a light source, but they also cause radiation damage that's hard to get rid of.

### Processing materials

Current semiconductor intermetal processes provide a final dielectric topography that's smooth, but not perfectly flat. With new devices needing three or four levels of metallization, the one or two insulating layers between each pair of metal conductors must be absolutely flat.

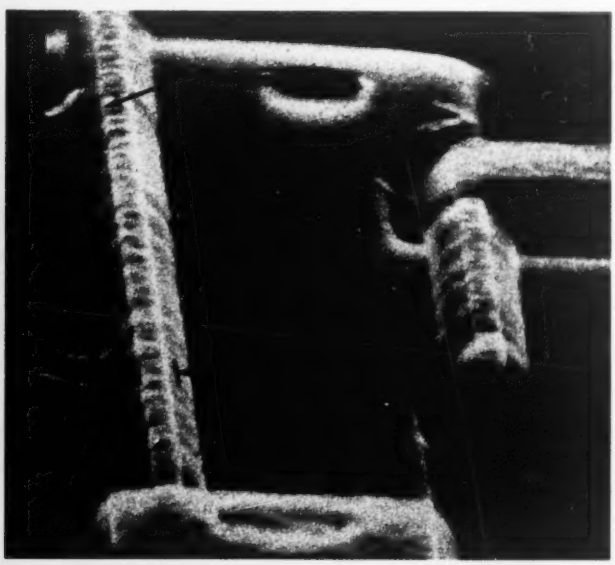
No current process provides complete flatness (planarization), but IBM, Sematech, and some Japanese companies have tried




**The ever decreasing dimensions of thin film depositions in multilayer semiconductor circuits require continual development of new materials and deposition processes.**

1. Epitaxial layer
2. Trench isolation
3. Planarized intermetal dielectric
4. Sidewall spacer
5. Metal 1
6. Interlayer dielectric
7. Tungsten plug
8. Metal 2
9. Passivation
10. Polycide gate electrode
11. Field oxide
12. Source/drain
13. Trench

*Figure courtesy of Applied Materials*



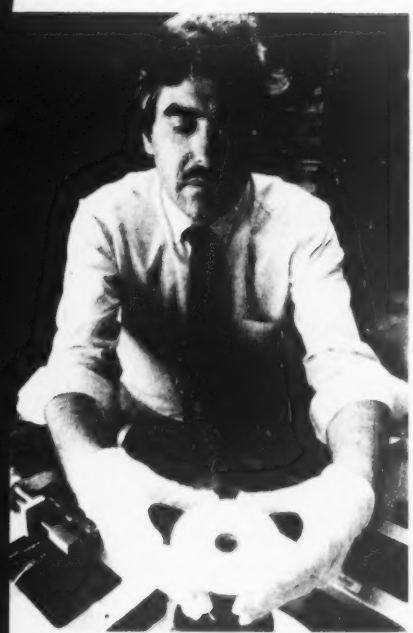
**IBM used electron-beam lithography to make this FET (left) which demonstrates basic feasibility of 10-Gbit memory chips.**

**The center of this clear polycarbonate disk (right) has OCLI's antireflection coating that also resists abrasion damage in the coated area.**

to grind the layers to get flatness.

"A more elegant solution is to perform this process in a deposited etchback manner," says Patrick Thomas, marketing director for advanced deposition technology at Applied Materials, Santa Clara, CA. "We deposit $B_2O_3$ that flows as it's being deposited and can give a 100-μm layer with only a 2- to 3-deg slope."

TEOS (tetraethylorthosilicate) has been used to deposit advanced semiconductor dielectrics because of its more uniform coating ability, while silane ($SiH_4$) has been the traditional source material for production coatings. However, the complexity of submicrometer devices is forcing researchers to replace silane with TEOS.



IBM scientist Ian Sanders holds a thin-film coated magnetic disk etched with 0.5-μm-wide circular tracks and capable of holding up to 10-Gbits of data.

### Hard coatings

Most hard coatings are based on nitride and carbide thin-film coatings. A new material being developed is titanium aluminum nitride.

"The reason this material is so interesting is that it keeps the cubic structure of titanium nitride, but has much higher oxidation resistance," says William Sproul, a researcher at Northwestern University's Basic Industry Research Laboratory, Evanston, IL.

Titanium aluminum nitride can be used in high-temperature wear applications where you're concerned about converting from a nitride to an oxide. In the 50%-50% titanium-aluminum ratio, the coating is harder than either TiN or AlN.

Sputtering is an ideal process for depositing these coatings because maintaining alloy ratios is easier than with other processes. An evaporative process, for example, would vaporize the aluminum in the target well before the titanium is vaporized.

Although cutting tools have had monolayer TiN and TiC thin-film coatings for several years, advancements in coating adhesion are improving these products.

Kennametal Inc., Latrobe, PA, makes cutting tools that have between two and 13 thin-film coatings. The tool substrate (WC) has alternating layers of TiN, $Al_2O_3$, and TiCN. By controlling the use of these materials, tools can be designed for specific applications. The abrasion resistance of TiC and TiCN, $Al_2O_3$'s chemical inertness and insulative characteristics, and TiN's lubricity are considered when designing these tools.

### Optical coatings

Antireflection, abrasion, and protective thin films commonly applied to glass can also be applied to flexible plastic optics in submicrometer to 50-μm thicknesses.

Optical Coating Laboratory Inc., Santa Rosa, CA, uses ion beams to deposit materials on plastics at or near room temperature, which eliminates optical distortion and increases the coating's durability.

One application for this process is as a laser rejection coating for protective eyewear. The coating performance, $10^{-3}$ to $10^{-4}$ rejections, is limited from the ideal performance of $10^{-5}$ to $10^{-6}$ rejections by stress levels in the plastic substrate, not

### Putting the film down

SELECTING the best deposition technique from the many available can be confusing. Here's a rundown of various methods and what's new with them:

- PVD (physical vapor deposition) applies films to substrates by evaporating or sputtering a source (target) and allowing the material to deposit on a substrate.

  To form compounds, both sputtering and evaporation can be performed with a reactive gas in an activating plasma.

  Ion plating is similar to sputtering, except the susbstrate is electrically biased, which causes a working gas such as argon to ion bombard the substrate, improve the coating adhesion, and change its surface microstructure.

  Ion implantation uses an ion beam accelerator to bombard a substrate with high-energy ions to dramtically change the surface characteristics of a substrate target. Electron cyclotron resonance (ECR) implantation provides improved control in this process.

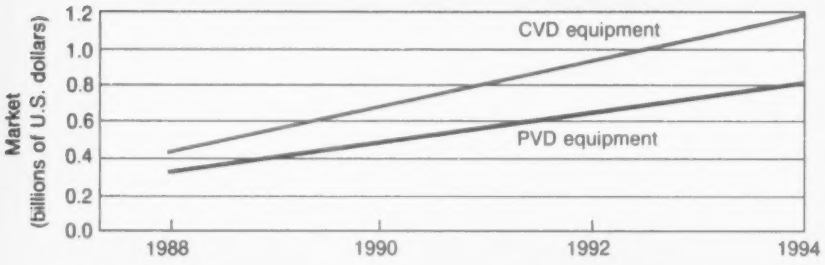
- CVD (chemical vapor deposition) flows gases over a heated substrate where they react to form a thin film. Most CVD processes are performed in vacuum, but newer methods allow coating in low- or atmospheric-pressure environments.

  Plasma-enhanced CVD (PECVD) processes can be used with RF- or photon-excited methods.

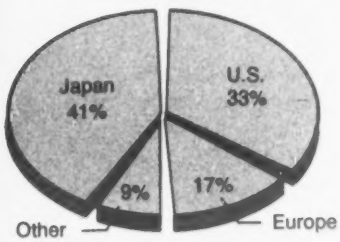
- Spin-on deposition drops liquid precursors on a spinning substrate for even distribution. This is followed by pyrolysis to cure the film. Spin-on methods can be performed in vacuum or nonvacuum environments and with materials such as glass and metal-organics.

- Dry-etch processes are replacing wet-etch methods due to better control, processing ease, and, most importantly, less pollution. Processes in use or development include reactive ion etch (RIE), ECR etch, magnetically enhanced ion etch (MIE), and sputter etch.

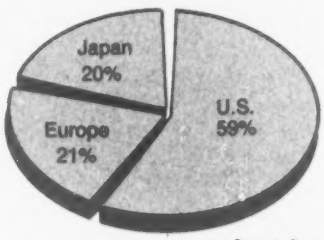
**Strong growth forecast for thin-film equipment**




**Who buys CVD equipment**




**Who makes CVD equipment**




Source: Dataquest

**U.S. companies dominate the CVD equipment market with more than $260 million in sales in 1988. However, that market share is expected to erode over the next several years according to Dataquest analysts.**

by thin-film materials or processes.

A 20% improvement in oxygen permeability over existing coatings also allows these coatings to be applied as protective barrier layers in packaging products.

### Magnetic media

IBM's Almaden Research Center, San Jose, CA, recently demonstrated 1-Gbit/in$^2$ storage media capability. This tenfold improvement over existing systems was made with a conventionally sputtered cobalt-platinum-chromium coating about 200-Å thick onto a 100-Å-thick chromium coating.

This system uses a 125-Å-thick carbon overcoat. Because this is only a third of the thickness of conventional protective coatings, more research is needed to determine if it provides adequate protection.

Research also is being performed on magnetoresistive recording heads, which could replace conventional inductive heads. "The potential for structures with very high resistance changes exists, which transducers in the future will rely on to generate readback signals," says Ian Sanders, manager of IBM's magnetic storage research.

### Superconducting thin films

Various thin-film approaches are being used to fabricate high-temperature superconducting (HTS) materials. An integrated MOCVD (metal-organic CVD) process that continuously deposits yttrium-barium-copper HTS thin films on flexible fibers has been developed by researcher Jack Lackey at Georgia Institute of Technology, Atlanta.

By depositing the superconducting material on a flexible fiber Lackey can bypass the basic brittleness problems of HTS materials and make wires that are flexible.

"Yttrium-based superconductors have fewer processing problems and are closer to applications," says Antonio Mogro-Campero at General Electric's Corporate R&D, Schenectady, NY. Thallium films have the highest superconducting temperature (125 K) but are very hard to process due to thallium's tendency to migrate out of its deposition layer after thermal processing.

Depending on the application, Mongro-Campero uses coevaporation, sputtering, chemical-precursor, or MOCVD to deposit HTS materials.

### Integrating systems

By connecting several vacuum deposition processes together, improvements in the quality and characteristics of thin films can be obtained by eliminating the potential for air contamination between processing steps. The MBE Center at Univ. of Illinois, Champaign, uses seven interconnected MBE chambers with a UHV racetrack that allows researchers to move their test materials from one chamber to another without breaking a vacuum.

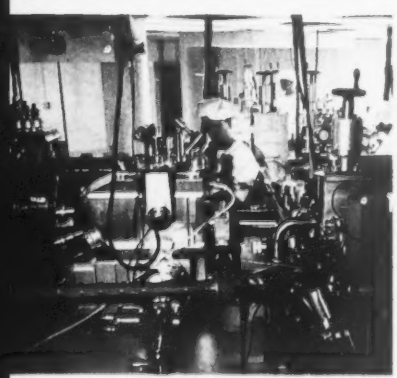
A process developed by engineers at Nippon Steel Corp., Kawasaki, Japan, combines plasma-assisted CVD with sputtering, ion plating, and ion bombardment for deposition of multiple thin films on a continuous metal coil. This process allows deposition of improved corrosion-resistant coatings, electrically insulated coatings, and a wide range of abrasion-resistant coatings.

### Measuring thin films

Few improvements in thin-film measuring methods have been made during the past decade. Routine measurements include:

- x-ray diffraction to determine what phases are present
- Auger and SEM to determine microstructure, surface structure, grain size, and porosity
- ESCA or XPS for surface chemical analysis
- microindenter for hardness.

Most product-specific test methods require sophisticated equipment and highly trained personnel to operate them. These limitations don't lend themselves to development into generalized analytical products. R&D



**Univ. of Illinois' MBE facility eliminates air contaminants by transferring samples in UHV tubes between film growth chambers.**

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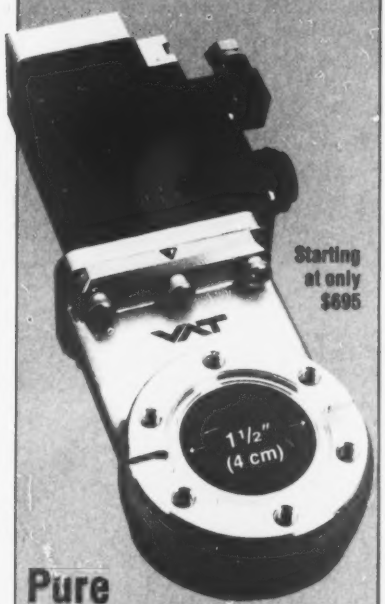


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